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(71) Applicant *(for all designated States except US)*: STIG G. CARLQVIST MOTOR CONSULTANT (C.M.C.) AKTIEBOLAG [SE/SE]; Sånekullavägen 43, S-217 74 Malmö (SE).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)* : HAVER, Eitel, Fritz [DE/DE]; Von Düesberg-Strasse 1, D-4740 Oelde (DE). CARLQVIST, Stig, G. [SE/SE]; Sånekullavägen 43, S-217 74 Malmö (SE).

(74) Agent: AWAPATENT AB; Box 5117, S-200 71 Malmö (SE).

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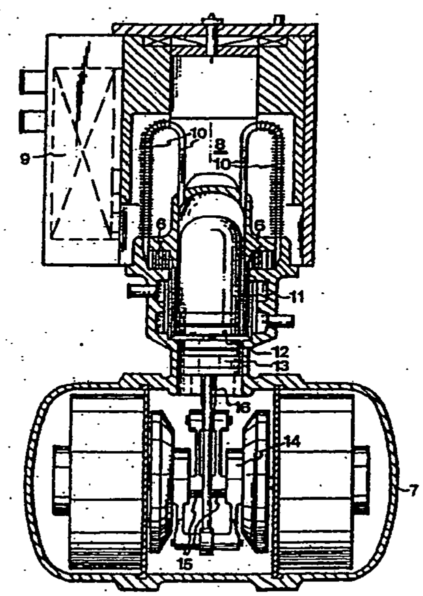
(57) Abstract

An energy converter working according to e.g. the Stirling cycle has a cold side, a hot side and, arranged therebetween, an annular regenerator (6) through which passes a flow path for the working gas of the converter. This path is substantially radially directed and has an increasing flow area in the direction from the cold side to the hot side. A heating device especially adapted for use as a regenerator in such an energy converter has an inner layer consisting of at least one strip of coarse wire netting; a coil arranged on the inner layer and having a plurality of turns of at least one strip of fine wire netting; and an outer layer wound round the coil and consisting of at least one strip of coarse wire netting. In a method of making such a heating device, an inner layer is formed of at least one strip of coarse wire netting; a coil with a plurality of turns of at least one strip of fine wire netting is wound round the inner layer; and an outer layer of at least one strip of coarse wire netting is wound round the coil.



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ENERGY CONVERTER WITH ANNULAR REGENERATOR, ANNULAR HEATING DEVICE, AND METHOD OF MAKING THE HEATING DEVICE

This invention is directed at an energy converter working according to the Stirling cycle, the Ericsson cycle or a similar thermodynamic cycle, and having a cold side, a hot side and, arranged therebetween, an annular regenerator through which working gas is alternately conducted from the cold side to the hot side, and vice versa, in one and the same flow path.

The invention further concerns an annular heating device especially adapted for use as a regenerator in such an energy converter, as well as a method of making this heating device.

It is well-known in the art to arrange annular regenerators round the cylinders of single-cylinder or multi-cylinder energy converters of e.g. Stirling type. This arrangement is advantageous in that the piston and the regenerator can be enclosed in the same pressure vessel, which facilitates sealing the pressure vessel and contributes to reducing the dimensions and weight of the energy converter.

A disadvantage is that the flow path of the working gas through the regenerator runs parallel to the centre axis of the cylinder, quite regardless of the temperature-dependent expansion of the working gas on the way to the hot side of the energy converter and the contraction of the gas on the way to the cold side of the converter. This entails considerable variations in the speed of the working gas passing through the regenerator, and prevents efficient use of the heat transfer capacity of the regenerator material.

Another disadavantage is that regenerators of this type are very expensive to manufacture because a considerable amount of the netting forming part of the regenerator goes to waste.

In a prior art method of making an annular multilayer heat accumulator or heat exchanger, centrally apertured discs are first punched from a wire netting and superimposed to form a stack which is then subjected to pressure in a press device to interconnect the apertured wire netting discs. Subsequently, the stack is fixed by sintering so that it will keep the desired shape.

When the centrally apertured discs are punched from the wire netting, there is a waste of up to 70%.

One object of the invention is, therefore, to provide an energy converter with optimum heat transfer conditions in the regenerator caused by the restrictions on the temperature-dependent variations in speed of the working gas flowing through the regenerator.

This object is achieved in that the flow path of the working gas through the regenerator is substantially radially directed and has an increasing flow area in the direction from the cold side to the hot side.

Another object of the invention is to provide an annular heating device with optimum heat transfer conditions, which is much less expensive to make than prior art annular heating devices.

This object is achieved by an annular heating device which is characterised by an inner layer consisting of at least one strip of coarse wire netting; a coil arranged on the inner layer and having a plurality of turns of at least one strip of fine wire netting; and an outer layer wound round the coil and consisting of at least one strip of coarse wire netting.

A further object of the invention is to provide a method of making such a heating device. This method minimises the waste of the wire netting forming the basic material and makes it possible to manufacture annular heating devices of the same height but of different diameters by using one or more wire netting strips of the same width.

This object is achieved by a method which is characterised in that an inner layer is formed of at least one strip of coarse wire netting; that a coil with a plurality of turns of at least one strip of fine wire netting is wound round the inner layer; and that an outer layer of at least one strip of coarse wire netting is wound round the coil.

The preferred embodiments of the invention will be described in more detail below with reference to the accompanying drawings, in which

Fig. 1 is a schematic view of a known annular heating device, such as a regenerator, a heat accumulator and a heat exchanger;

Fig. 2 is a schematic section of a heating device in the form of an annular regenerator according to an embodiment of the invention;

Fig. 3 is a schematic section of the regenerator in Fig. 2 provided with an insulating layer;

Fig. 4 is a part section of a Stirling machine provided with the annular regenerator in Fig. 2;

Fig. 5 is a section of part of the Stirling machine provided with an annular insulated regenerator according to another embodiment of the invention;

Fig. 6 is a section of an annular heating device according to an embodiment of the invention; and

Fig. 7 is an enlarged section of part of the heating device in Fig. 6.

In use, a gaseous or liquid medium is conducted through the known heating device 1 shown in Fig. 1, from the hot upper side to the cold lower side. The medium moves in the direction of the arrows. As can be seen, no arrangements are made to counteract the temperature-dependent change in volume of the medium, which in turn entails considerable variations in speed, thus preventing efficient use of the heat transfer capacity of the heating device material.

Fig. 2 illustrates an annular regenerator 2 forming part of an energy converter of Stirling type. In this regenerator, on the other hand, the medium, which is a pressurised working gas, flows substantially radially. Since the axially directed openings 3, 4 of the regenerator 2 toward the hot side and the cold side, respectively, of the energy converter are arranged at a radially outer and a radially inner location, respectively, the flow path of the working gas widens from the cold lower side to the hot upper side. This equalises the flow rate of the working gas, thus enabling a much more efficient use of the heat transfer capacity of the regenerator material.

Fig. 3 illustrates how this regenerator can be insulated in a manner enhanced by the radial flow geometry, thus reducing the heat losses and increasing the efficiency of the energy converter. Thus, the insulating layer 5 is thicker between hot parts of the regenerator and cold parts of the energy converter, as well as between cold parts of the regenerator and hot parts of the energy converter.

Fig. 4 illustrates a regenerator 6 of purely radial geometry, which is incorporated in a single-cylinder Stirling engine of displacement type to which heat is to be supplied by burning gaseous fuel. The mechanical power generated is used for driving counterrotating electric generators incorporated in the crankcase 7. In this manner, the engine can be hermetically sealed without the use of external, moving seals. High-temperature combustion gases are generated in the combustion chamber 8. The heat content of these gases is supplied to the engine by heat transfer, and the residual heat is utilised in an air preheater 9 serving to preheat incoming air to the combustion chamber. Through the heat pipes 10, the heat is conveyed, via the working gas which mostly is helium or hydrogen, to the regenerator 6 which in this case is purely radial, with the hot working gas at the larger

radius and the cold working gas at the smaller radius. The heat that cannot be converted to useful work is disposed of in the radiator 11 which usually is cooled with water in a conventional external radiator system. The gas is transferred from the hot part of the engine to the cold part, and vice versa, by means of the displacement piston 12, while the cold gas is compressed and the hot gas is expanded by means of the working piston 13 which in turn tranfers the mechanical useful work to the mechanism 14 via the piston rods 15. Via a second piston rod 16, this mechanism also controls the displacement piston 12. Finally, the mechanism 14 is enclosed by the crankcase 7 which here is pressurised with the mean pressure of the working gas, thus hermetically sealing the engine.

Fig. 5 illustrates another embodiment of the invention, in which the regenerator 17 has a combined radial and axial throughflow. Also in this case, we are dealing with a single-cylinder Stirling engine of displacement type with two pistons in the cylinder. Only the engine part adjacent to the regenerator 17 is shown in the Figure. The combustion chamber is designated 18. The combustion gas passes first a row of heat pipes 19 with non-enlarged surfaces, then another row of heat pipes 20 whose surfaces are enlarged by means of flanges. The heat pipes communicate with the regenerator 17 at the outer radius thereof. The design of the regenerator 17 gives the working gas a comparatively uniform flow rate, thus increasing the efficiency of the regenerator. Owing to the geometry of the regenerator 17, the thermal insulation 21 can be used optimally, inter alia by the provision of a large insulating layer between adjacent hot and cold parts. The radiator 22 receives cold gas and maintains it so during the compression of cold gas. Further, there is a displacement piston 23 with a heat-insulating dome 24 of thin non-corrosive sheet metal. The working piston 25 is disposed below the displacement piston 23.

Fig. 6 illustrates an annular heat accumulator or heat exchanger which is wound of wire netting strips and which has been fixed by sintering into a dimensionally stable body. This annular body comprises an inner layer 26 and an outer layer 27, which both may be made of coarse wire netting. The coarse wire netting of the inner layer may, for instance, be a filter netting of RPD-type (Reverse Plain Dutch Weave) with 50 x 14 wires/cm and a wire diameter of 0.20-0.40 mm. The outer netting may, for example, be a filter netting of SPW-type (Single Plain Dutch Weave).

A coil 28 is arranged between the inner layer 26 and the outer layer 27, and consists of a plurality of turns of one or more strips of fine wire netting with identical or different openings.

The strips of fine wire netting may be of different types for example having rectangular, e.g. square, openings. These strips may have approximately 40-100 wires/cm and a wire diameter of 0.10-0.04 mm, and be formed with openings of 0.200-0.063 mm.

The number of turns of the coil 28 depends on the type of wire netting and the fill factor. The fill factor is a function of the weight of the material of the heat accumulator or the heat exchanger in relation to the weight of a massive ring. The fill factor is 20-60%.

In the embodiment shown in Figs 6 and 7, the end sides 29, 30 of the annular heat accumulator or heat exchanger are surrounded by annular lids of U-shaped cross-section.

Usually, the outer diameter (Da) of the heat accumulator or heat exchanger is 50-250 mm, and the inner diameter (Di) amounts to 50-75% of the outer diameter.

As mentioned above, a medium can flow through the heat accumulator or heat exchanger in the direction of the arrows shown in Fig. 6 or, in other words, from the inside to the outside, or from the outside to the inside in radial direction. A heated gaseous medium is supplied from

the outside and inwards through the heat accumulator or heat exchanger, the temperature of the medium decreasing from e.g. 600°C to 90°C. At the outer circumference, there is a larger wire netting surface for the incoming hot medium than at the inner circumference for the outgoing cooled medium. During the subsequent cycle, the heat accumulator or heat exchanger emits the heat recovered from the medium, and the medium which is to be heated is supplied from the inside and outwards through the heat accumulator or heat exchanger. In single-cycle operation, the heat accumulator or heat exchanger is also capable of storing heat for some time.

The use of the above heating devices with a substantially radial flow path is not restricted to the energy converters shown in Figs 4 and 5, and these heating devices may advantageously be used in other energy converters, both single-cylinder and multi-cylinder ones, as well as in heat pumps or refrigerating installations with a closed helium circuit instead of environmentally dangerous freon.

CLAIMS

1. An energy converter working according to the Stirling cycle, the Ericsson cycle or a similar thermodynamic cycle, and having a cold side, a hot side and, arranged therebetween, an annular regenerator (2, 6, 17) through which working gas is alternately conducted from the cold side to the hot side, and vice versa, in one and the same flow path, characterised in that the flow path is substantially radially directed and has a flow area which increases in the direction from the cold side to the hot side.

2. The energy converter of claim 1, characterised in that the annular regenerator (2, 6, 17) is substantially made up of one or more fine-mesh netting strips wound in the circumferential direction of the regenerator.

3. The energy converter of claim 2, characterised in that each turn of the fine-mesh netting is offset in one and the same axial direction relative to the turn immediately beneath.

4. An annular heating device especially adapted for use as a regenerator in the energy converter of claim 1, characterised by an inner layer (26) consisting of at least one strip of coarse wire netting; a coil (28) arranged on the inner layer (26) and having a plurality of turns of at least one strip of fine wire netting; and an outer layer (27) wound round the coil (28) and consisting of at least one strip of coarse wire netting.

5. The heating device of claim 4, characterised in that the coil (28) comprises a plurality of types of strips of fine wire netting.

6. The heating device of claim 5, characterised in that the strips of fine wire netting have different openings.

7. The heating device of any one of claims 4-6, c h a r a c t e r i s e d in that the strip or strips of fine wire netting are uniformly stretched.

8. The heating device of any one of claims 4-6, c h a r a c t e r i s e d in that the strip or strips of fine wire netting are differently stretched.

9. The heating device of any one of claims 4-8, c h a r a c t e r i s e d in that the inner layer (26) and the outer layer (27) each consist of coarse wire netting with rectangular, e.g. square, openings.

10. The heating device of any one of claims 4-8, c h a r a c t e r i s e d in that the inner layer (26) and the outer layer (27) each consist of filter netting.

11. The heating device of any one of claims 4-10, c h a r a c t e r i s e d in that the coil (28) has end sides (29, 30) surrounded by annular lids (31) U-shaped in cross-section and surrounding also part of the inside and the outside of the heating device.

12. The heating device of any one of claims 4-11, c h a r a c t e r i s e d in that at least some parts of the heating device are sintered.

13. A method of making the heating device of claim 4, c h a r a c t e r i s e d in that an inner layer (26) is formed of at least one strip of coarse wire netting; that a coil (28) with a plurality of turns of at least one strip of fine wire netting is wound round the inner layer (26); and that an outer layer (27) of at least one strip of coarse wire netting is wound round the coil (28).

14. The method of claim 13, c h a r a c t e r - i s e d in that the coil (28) is wound of a plurality of strips of fine wire netting.

15. The method of claim 14, c h a r a c t e r - i s e d in that the coil (28) is wound of strips of one type of fine wire netting or of two or more types of fine wire netting with different openings.

16. The method of any one of claims 13-15, c h a - r a c t e r i s e d in that the coil (28) is wound in such a manner that the strip or strips of fine wire netting are uniformly stretched.

17. The method of any one of claims 13-15, c h a - r a c t e r i s e d in that the coil (28) is wound in such a manner that the strip or strips of fine wire netting are differently stretched.

18. The method of any one of claims 13-17, c h a - r a c t e r i s e d in that the inner layer (26) and the outer layer (27) each are formed of coarse wire netting with rectangular, e.g. square, openings.

19. The method of any one of claims 13-17, c h a - r a c t e r i s e d in that the inner layer (26) and the outer layer (27) each are formed of filter netting.

FIG.1

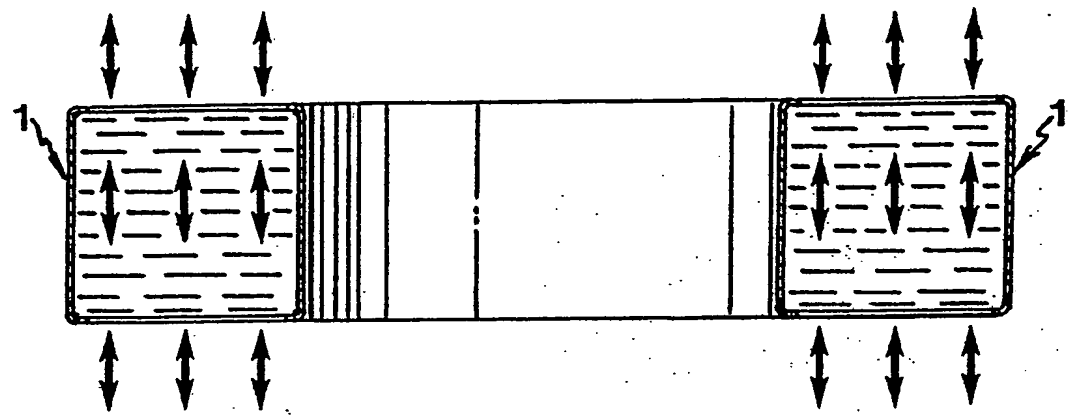

FIG.2

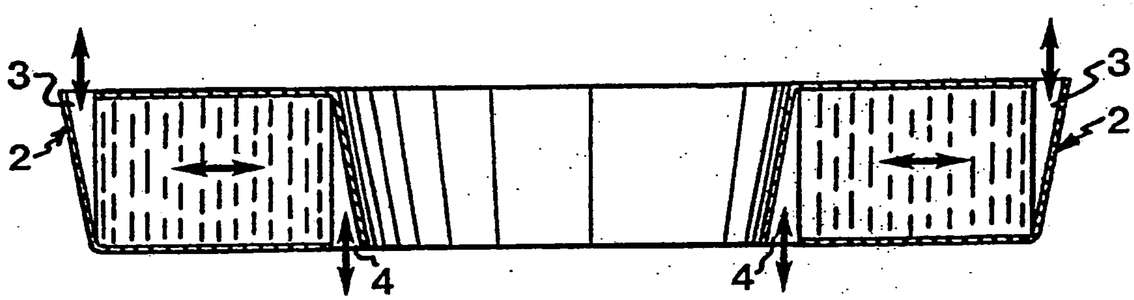

FIG.3

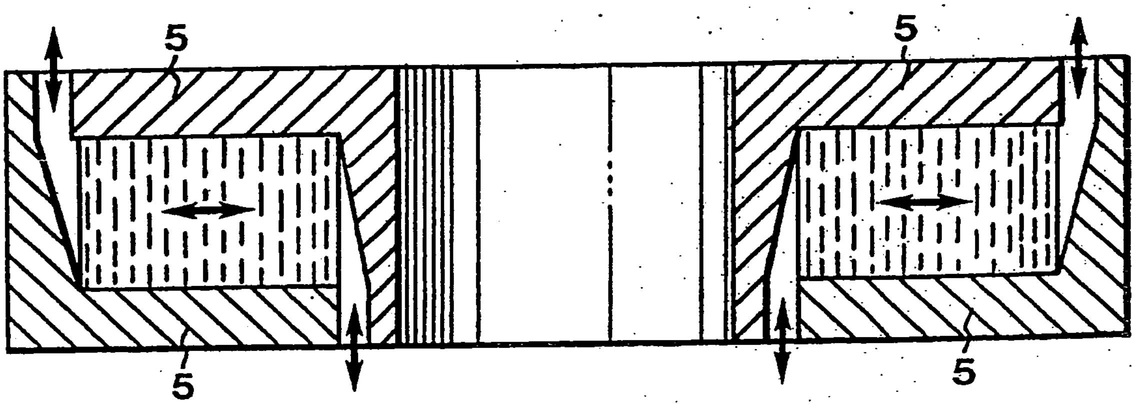

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FIG.4

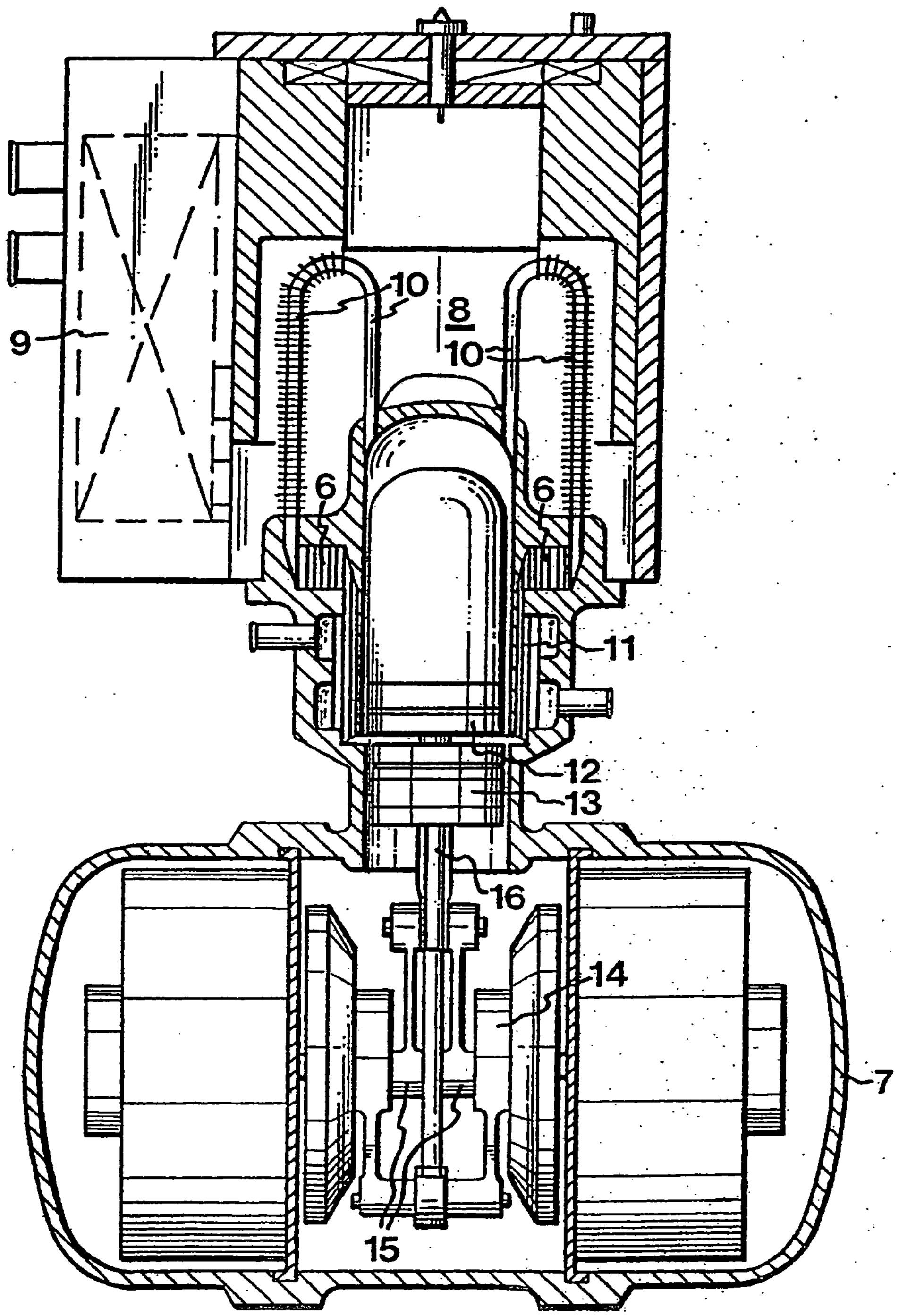


FIG.5

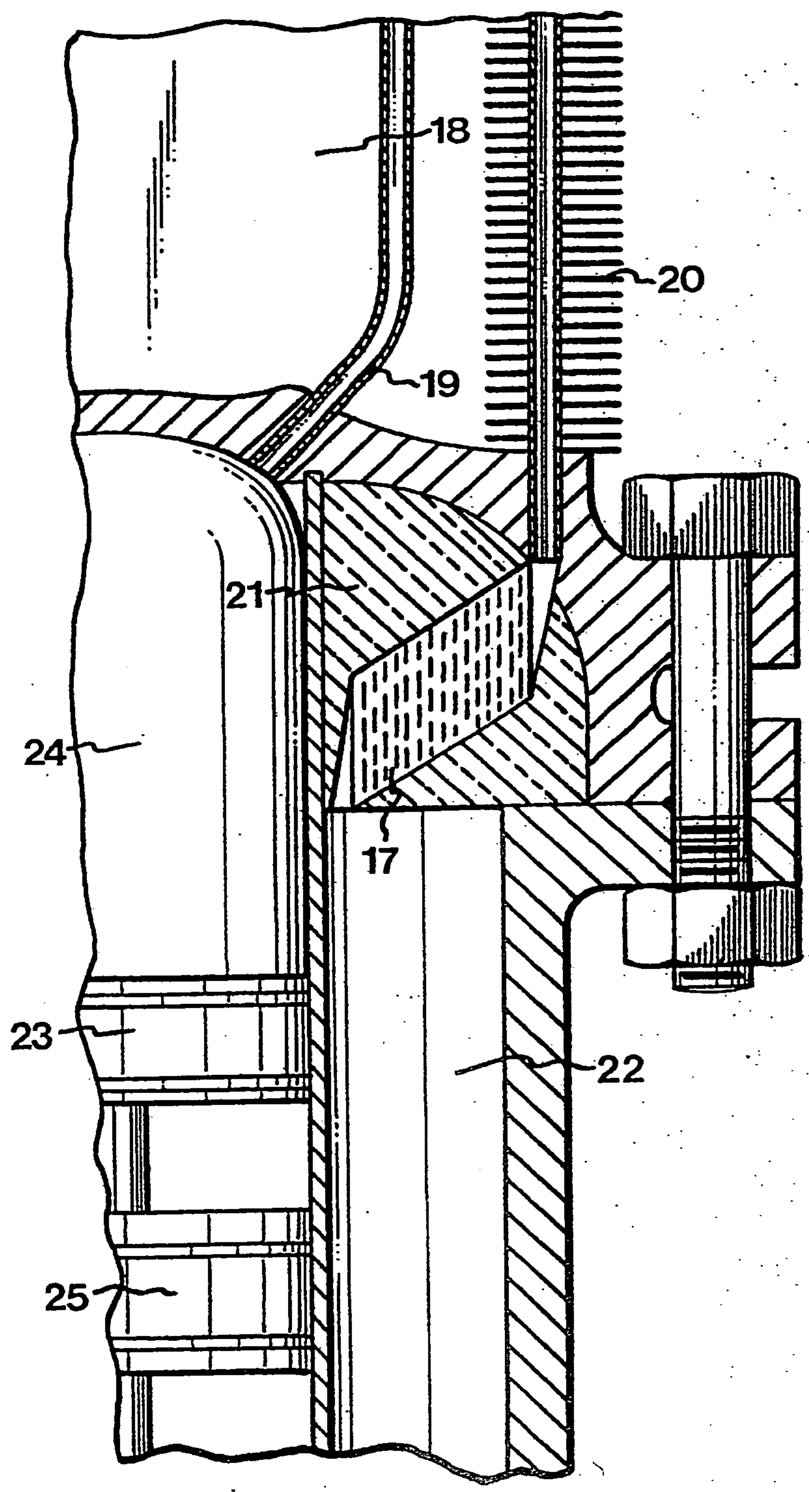


FIG.6

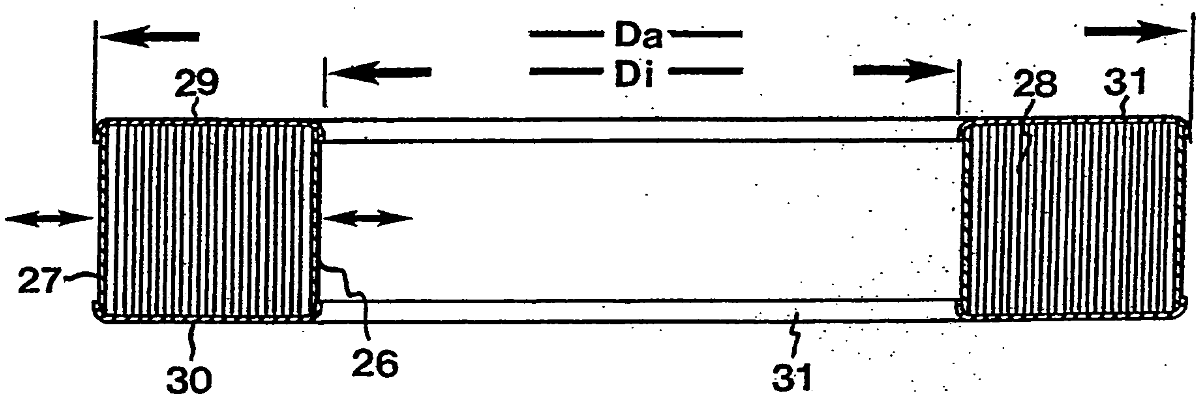
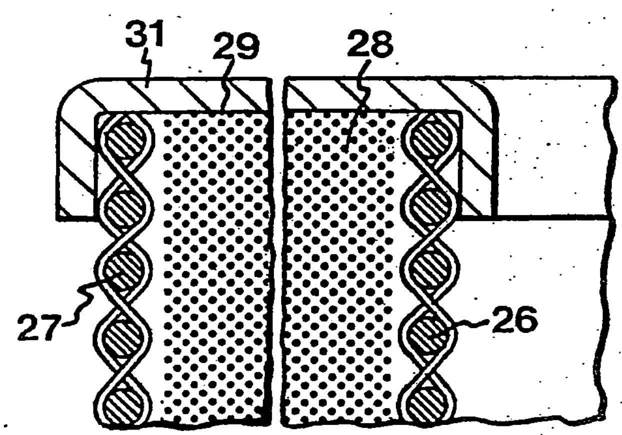


FIG.7



INTERNATIONAL SEARCH REPORT

International Application No PCT/SE 90/00672

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: F 02 G 1/057

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
IPC5	F 02 G

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched[8]

SE,DK,FI,NO classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category *	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
A	GB, A, 2187514 (COLGATE THERMODYNAMICS CO) 9 September 1987, see the whole document --	1-19
A	Patent Abstracts of Japan, Vol 9, No 135, M386, abstract of JP 60- 17256, publ 1985-01-29 (IKUO HORI) --	1-19

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
16th January 1991	1991 -01- 23
International Searching Authority	**Signature of Authorized Officer**
SWEDISH PATENT OFFICE	K. Bengtsson Krister Bengtsson

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ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.PCT/SE 90/00672

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A- 2187514	87-09-09	AU-D- 6450386	87-04-30
		CA-A- 1247377	88-12-27
		DE-A- 3636831	87-04-30
		JP-A- 62217063	87-09-24
		US-A- 4619112	86-10-28